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ANALYSIS OF THE TIME RELATIONSHIPS IN DIRECT  
BALLISTOCARDIOGRAPHY RATE

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- USSR -

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# ANALYSIS OF THE TIME RELATIONSHIPS IN DIRECT BALLISTOCARDIOGRAPHY RATE

[Following is the translation of an article by M. N. Tumanovskiy and Yu. D. Safonov entitled "K analizu vremennykh sootnosheniy v pryamoym ballistokardiografii skorosti" (English version above) in Klinicheskaya Meditsina (Clinical Medicine), Vol. XLI, No. 6, Moscow, 1960, pages 60-66.]

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The ballistocardiogram, like any graphic curve reflecting movement, has three parameters: displacement, rate, and acceleration. The ballistocardiogram of displacement is less suitable for demonstrating the nature of the process, since it does not detect high-frequency components of greater rate than the basic recordable frequencies. The "pure" ballistocardiogram of rate is valuable in that it records the high-frequency vibrations of the human body which depend, in pathologic cases, on disturbances in hemodynamics. The ballistocardiogram of acceleration is even more sensitive in this respect. The ballistocardiogram of rate, having these valuable properties, is advantageously distinguished from the curve of acceleration by the fact that the method of obtaining it is simpler.

An electromagnetic device of the Dock-Parin type, which detects the necessary movements for the ballistocardiogram of rate, is available to any therapeutic institution. There are methods of obtaining ballistocardiograms of all three parameters with one electromagnetic device, by means of electrical integration of the curve of rate to the curve of displacement and differentiation of the rate curve to the curve of acceleration (G. Ye.

Tsinsadze, Smith and Bryan). But these are not as yet in wide use. The extreme sensitivity of the electromagnetic devices to electrical and mechanical oscillations of small amplitude and high frequency (surface mechanical vibrations, muscle tremors, alternating currents, and so forth) requires all investigators to use electrical filters which reduce the frequency characteristics of the ballistocardiograph (V. V. Parin and A. V. Mareyev; A. I. Gifter and associates; Dock and Taubman; Dock, G. Mandelbaum and K. Mandelbaum; Porcy and others).

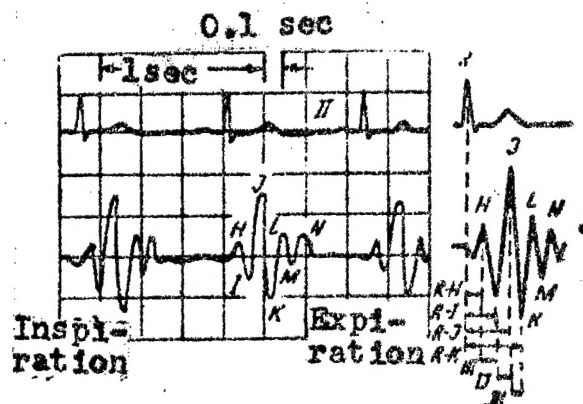


Fig. 1. Ballistocardiogram of a healthy 27-year old male taken at the same time as an electrocardiogram recorded from lead II. To the right is the scheme of time analysis of the systolic waves of the ballistocardiogram.

In our studies we recorded the "pure" ballistocardiogram of rate (with electrical filter). Under these conditions, elimination from the above-mentioned contaminating influences is a problem. We solved this problem by using a mechanical (not an electrical) damper and a two-channel recording device of special construction (Yu. D. Safonov) which, in the presence of undistorted recording of frequencies in the range of 0.3 to 120 c/s, does not respond to superficial electrical interferences of this frequency. This permitted us to detect by ballistocardiography the various irregularities, splittings, and dupli-

cations of waves associated with pathological hemodynamic disturbances.

Analysis of ballistocardiograms by the majority of investigators has been confined to a determination of the degree of pathology represented by them, according to Brown and de Lalla, and to a determination of certain peculiarities in the form and basic time relationships (V. V. Parin, A. I. Geffer and associates, S. S. Belousov, G. A. Vitenshtaynas, Ling-chen, A. M. Kochetov, Dock, G. Mandelbaum and K. Mandelbaum).

In analyzing the time relationships obtained in our studies, we came to the conclusion that a precise computation of the time components of the ballistocardiogram is of great clinical importance.

Ballistocardiographic studies were carried out by us in 100 healthy subjects aged 14 to 60 years, and in 320 patients with different cardiovascular diseases (of these, 120 had vascular heart disease and 80 had coronary insufficiency). Registration of the ballistocardiogram was effected with a two-channel ink-writing electrocardiograph (with a sensitivity of one mv = five mm) simultaneously with one of the leads of the electrocardiogram (at one mv = ten mm).

Fig. 1 shows a normal ballistocardiogram and the scheme of time analysis. In pathologic cases, with splitting or duplication of the waves of the ballistocardiogram, computation of time was carried to the second component of the split or duplicated wave.

The data of the time relationships obtained in healthy persons are shown in the table.

Table

	Time in seconds				
	R-H	R-I	R-J	R-K	H-I
Average	0.06-0.1	0.11-0.14	0.19-0.24	0.25-0.33	0.04-0.07
values	0.072	0.123	0.205	0.278	0.051

(at a frequency of cardiac contraction of not more than 80 to 85 beats per minute)

Table  
(continued)

	Time in seconds				
	IJ	JK	KL	LM	MN
Average	0.07-0.1	0.06-0.1	0.07-0.1	0.05-0.1	0.06-0.09
values	0.082	0.076	0.081	0.068	0.07

(at a frequency of cardiac contraction of not more than 80 to 85 beats per minute)

The data shown in the table are slightly (by 0.02 to 0.03 seconds) "faster" than the data of other authors (A. I. Geffer and associates, Scarborough et al, Dock, G. Mandelbaum and K. Mandelbaum) but do not differ from the data of Smith, who used a "pure" ballistocardiographic method for determination of rate. The cause of this is to be sought in the absence of electrical filtration in our studies. Electrical filters, as is known, by introducing a phase shift, cause a slight "retardation" of the wave of the ballistocardiogram beyond the R wave of RCG. Moreover, we count the time of the ballistocardiographic wave from the R wave, whereas the majority of foreign authors start from the Q wave of the ECG. The Q wave is almost never

abvious, and we believe that it is more suitable, in a practical sense, to start with the apex of the R wave.

Some authors report still shorter intervals of time for the components of the ballistocardiogram (by 0.01 to 0.015 seconds). Basically this pertains to the R-H and R-J intervals (V. V. Parin, R. M. Bayevskiy). It is probable that this may be due to the predominance of subjects of older or younger ages in the group studied, the number of subjects, and the presence or absence of trained athletes in the group. In all such instances, there is a rather marked variation in the time relationships of the ballistocardiogram, either to the shorter or to the longer side. In our group of 100 healthy persons, there were 12 athletes, among whom there was ordinarily bradycardia with time intervals longer than in untrained subjects. In computing the average values, this led to a prolongation of them, despite the "accelerating" effect of the absence of electrical filtration in our studies.

Moreover, the data of R. M. Bayevskiy were obtained under field conditions in which the studies were carried out following an inadequate period of rest, and physical stress, as is known, shortens the time of the ballistocardiographic waves.

In the majority of our patients (70 percent) with mitral insufficiency, and hence with splitting of the H wave, there was a prolongation of the R-H time to 0.13 to 0.15 seconds and a shortening of the H-I time to 0.03 seconds (Fig. 2). This disturbance was noted most frequently in the complexes on expiration. After physical exertion the percentage of instances in which this occurred on the ballistocardiogram increased (to 85 percent). The appearance of a second peak of splitting of the H wave is interpreted by us to be the result of an additional movement of the body of the patient in the direction of the head, caused during the phase of ventricular contraction by the reverse flow of blood from the left ventricle into the left atrium. Since this "reverse expulsion" continues into the phase of expulsion, it overlaps in time the subsequent phase, shortening it on the graphic recorder (lengthening the R-H interval shortens the H-I interval).

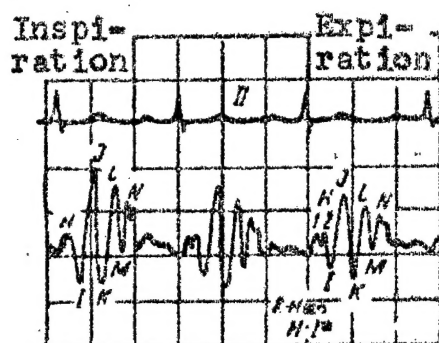


Fig. 2. Ballistocardiogram of patient M., 19 years of age, with mitral insufficiency. Upon expiration there is splitting of the H-wave with prolongation of the R-H interval to 0.13 second and shortening of the H-I interval to 0.03 second.

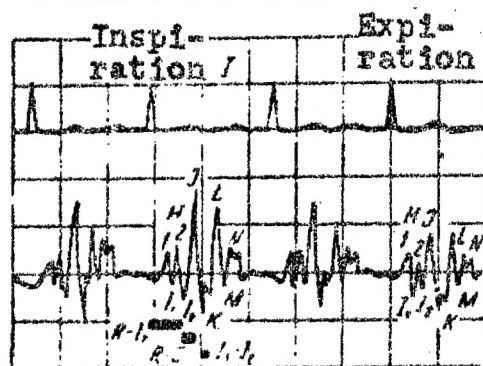


Fig. 3. Ballistocardiogram of patient B., 27 years of age, with a diagnosis of combined mitral valvular disease with predominance of insufficiency. There is splitting of the H and I waves.  $R-I_2 = 0.18$  second,  $I_1-I_2 = 0.05$  second,  $I_2-J = 0.05$  second. There is notching of the K-L segment.

M. S. Vovsi, using a dynamocardiogram in patients with mitral lesions, also remarks on the splitting of segment II of the dynamocardiogram, which reflects the phase of contraction of the ventricles. He regards this disturbance as a manifestation of asynchronism of the phase of ventricular contraction.

In 90 percent of patients with combined mitral valvular disease we observed splitting or duplication of the H and I waves with prolongation of the R-I time to 0.22 second. With predominance of stenosis, the length of the R-I segment was greater than with predominant insufficiency.

Splitting or duplication of the I wave of the ballistocardiogram was interpreted by us as an expression of asynchronism of ventricular contraction during the phase of rapid expulsion. The time between the first wave of expulsion ( $I_1$ ) and the second ( $I_2$ ) in mitral stenosis indicates, most likely, the time of delay of right ventricular contraction beyond that of the left ventricle; it may reach values of 0.08 second (Fig. 3 and 4). The ballistocardiogram in such cases assumes a unique form: the second peak of the H wave is, as it were, the first J wave, and the ordinary J wave appears to be the second J wave with shortening of the  $I_2$ -J<sub>2</sub> time to 0.04 to 0.05 second (see Fig. 4).

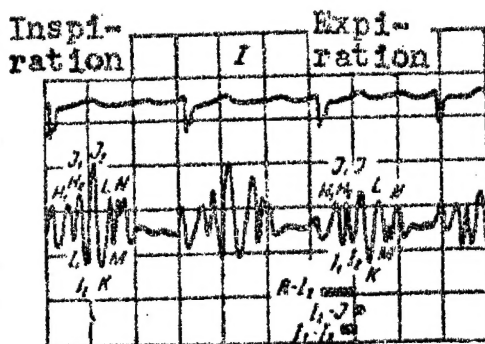


Fig. 4. Ballistocardiogram of patient B., 17 years of age. Diagnosis: combined mitral valvular disease with predominant stenosis.  $R-I_2 = 0.2$  second,  $I_1-I_2 = 0.08$  second,  $I_2-J_2 = 0.05$  second.  $H_2$  is simultaneous with  $J_1$ .

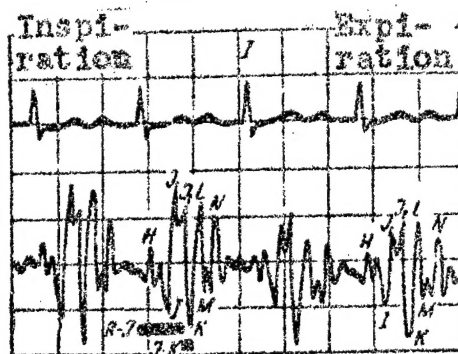


Fig. 5. Ballistocardiogram of patient A., 22 years of age. Diagnosis: mitral stenosis and aortic insufficiency. The I and J waves are split.  $R-J_2 = 0.26$  second,  $J_2-K = 0.04$  second (at a heart rate of 90 beats per minute).

Not infrequently it is possible to note that, in the complex during inspiration, when there is usually an increased systolic volume of the right ventricle, there is an increased amplitude of the second peak or of the second I and J waves ( $I_2-J_2$ ), and on expiration, when there is an increased systolic volume of the left ventricle, there is an increased amplitude of the first I and J waves ( $I_1-J_1$ ). In these patients (with  $I_1-I_2$  greater than 0.05 second), it is always possible to detect by auscultation a duplication or splitting of the second heart sound.

Asynchronism in the contraction of the right and left ventricles in patients with mitral stenosis is mentioned also by a number of other authors (Ye. B. Babitskiy, M. S. Vovsi, V. L. Karpman and G. V. Sadovskaya, using the dynamocardiogram, and by Bodrogi, using the ballistocardiogram and the phonocardiogram); the latter presented a ballistocardiogram similar to the one described by us (with two I and J waves).

Of course, this interpretation of the causes of

splitting of the H and I waves of the ballistocardiogram in lesions of the mitral valve is not beyond dispute. However, we believe it possible to state one of the more likely hypotheses, which unquestionably must be subjected to further investigation.

Moreover, in the ballistocardiogram in mitral stenosis we not infrequently have seen notching of the K-L segment with prolongation of the K-L time and splitting of the M and N waves, which is probably associated with asynchronism of the phases of ventricular filling.

In the ballistocardiogram of persons with aortic insufficiency (six patients), in addition to great amplitude of the I-J waves, we noted splitting of the J wave or notching of the J-K segment with prolongation of R-J<sub>2</sub> time to 0.26 to 0.3 second and shortening of the J<sub>2</sub>-K time to 0.04 second. This has invariably been accompanied by splitting of the diastolic M wave. Changes in the J wave are related, most likely, to quick reduction in pressure in the aorta at the end of systolic expulsion (phase of slow expulsion), and splitting of the M wave with reverse force created by the reverse flow of blood from the aorta into the left ventricle during the time of filling.

The presence in a patient of a second lesion, such as stenosis of the left venous ostium, does not obscure the ballistocardiographic picture of the aortic lesion, but merely adds the changes described in mitral stenosis (Fig. 5).

Splitting of the J wave in aortic insufficiency was earlier noted by Smith et al. in recording ballistocardiograms of rate and of acceleration, but was not seen by these investigators in ballistocardiograms of displacement.

We have already reported (M. N. Tumanovskiy and Yu. D. Safonov) on certain changes in the ballistocardiogram of rate in patients with different forms of coronary insufficiency.

In addition to determination of the degree of pathologic change in the ballistocardiogram, according to Brown and de Lalla, and to the forms of disturbances remarked upon by V. V. Parin, A. I. Gefen and associates, G. A. Vitenzhteynas, I. F. Kononenko and N. I. Shtel'makh.

Starr; Taymor, Wade et al, we found that in patients with coronary arteriosclerosis, despite considerable qualitative changes in the form of the ballistocardiogram similar to those seen in valvular lesions of the heart, no marked changes occur in the time relationships. Disturbances of the ballistocardiograms in patients with coronary arteriosclerotic angina pectoris and myocardial infarction were usually apparent as a splitting of the I and J waves, with out marked prolongation of the R-I and R-J times (as compared with healthy subjects). The  $I_1$ - $I_2$  or  $J_1$ - $J_2$  times never exceeded 0.04 to 0.05 second (Fig. 6 and 7). In these cases it was almost never possible to detect by auscultation a duplication of the first or second heart sounds.

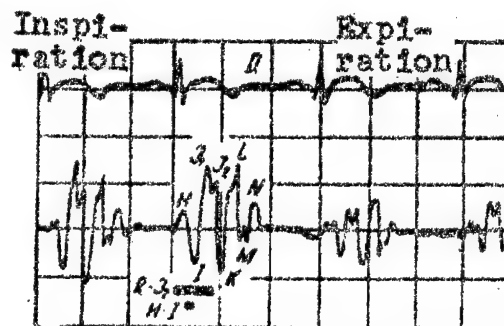


Fig. 6. Ballistocardiogram of patient S., 47 years of age. Diagnosis: myocardial infarction of the anterior wall of the left ventricle (of four weeks' duration). There is splitting of the J, L, and M waves.  $R-J_2 = 0.25$  second (normal).  $J_1-J_2 = 0.04$  second.

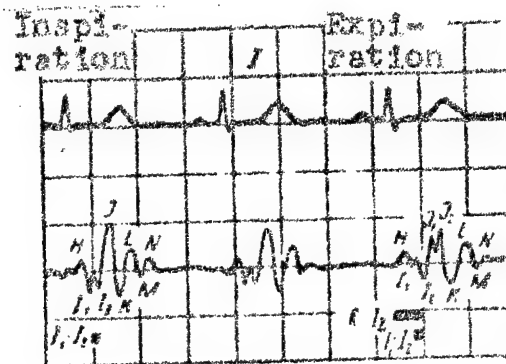


Fig. 7. Ballistocardiogram of patient G., 40 years of age. Diagnosis: coronary arteriosclerosis, angina pectoris at rest. There is splitting of the I wave on inspiration, and of I and J waves on expiration.  $R-J_2 = 0.12$  second.  $I_1-I_2 = 0.04$  second.

Splitting of the I wave in patients with coronary insufficiency is explained in the same way as in mitral stenosis, by asynchronism of the phase of quick expulsion, and splitting of the J wave by asynchronism of the increase in pressure in the aorta and pulmonary artery, which leads to non-simultaneous thrust of the blood against the arch of the aorta and the bifurcation of the pulmonary artery. In these ballistocardiograms, we have not infrequently been able to show that asynchronism in the cases mentioned is the result of delay in contraction of the left ventricle. This is confirmed by the fact that during inspiration there is an increase in the amplitude of the first peak of the split I and J waves, and during expiration an increase in amplitude of the second peak (see Figs. 6 and 7). It should be noted that the ballistocardiogram in patients with coronary insufficiency was much more frequently changed than the ECG. In cases in which the ECG and the ballistocardiogram were both normal, the latter was altered for a rather long time (two to four

days) after the attack of angina, whereas the ECG either remained normal or was altered only during the attack itself.

In response to physical exertion, the ballistocardiogram is also more sensitive than the ECG.

Sometimes, in patients with coronary insufficiency, together with splitting of the I and J waves there was splitting of the H wave, especially in the complexes during expiration (without especial prolongation of the R-H interval). In these cases we regarded this disturbance as a manifestation of asynchronism of the phase of ventricular contraction, probably due to asynchronism of pressure in the presence of a delayed increase in pressure in the left ventricle. Such a view is in agreement with the findings of M. S. Vovsi, who explains similar disturbances in the dynamocardiogram by asynchronism of the phase of contraction.

#### Conclusions

(1) Analysis of the time relationships in the ballistocardiogram of rate indicate marked disturbances in connection with the phases of cardiac activity. Duplication of the systolic waves of the ballistocardiogram, with prolongation of the time of the corresponding apices of the waves from the R wave of the ECG, may be looked upon as an expression of asynchronism in the activity of the ventricles.

(2) The ballistocardiogram reflects not signs of disease as such but rather signs of disturbances in hemodynamics, which may be encountered in different cardiovascular diseases.

(3) Of the direct methods of ballistocardiography, the most valuable for clinical purposes is the ballistocardiogram of "pure" rate, which demonstrates high-frequency components which tend to be eliminated with electrical filtration and are not recorded on the ballistocardiogram of displacement.

(4) Data obtained with the use of the unfiltered ballistocardiogram of rate correspond more nearly to the

findings obtained by other authors using other types of mechanical recordings (dynamocardiogram).

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